IN-32-CR
72907
P- 15

Finite Difference Time Domain Calculations of Antenna Mutual Coupling

by

Raymond Luebbers and Karl Kunz

Electrical Engineering Department
The Pennsylvania State University
University Park, PA 16802

April 1991

Abstract

The Finite Difference Time Domain (FDTD) technique has been applied to a wide variety of electromagnetic analysis problems, including shielding and scattering. However, the method has not been extensively applied to antennas. In this short paper calculations of self and mutual admittances between wire antennas are made using FDTD and compared with results obtained using the Method of Moments. The agreement is quite good, indicating the possibilities for FDTD application to antenna impedance and coupling.

I Introduction

The Finite Difference Time Domain (FDTD) technique has had only limited application to antennas. This is somewhat surprising, since the geometrical and material generality of the method suggests that it might have significant application to antenna analysis, especially in situations where other structures, especially electromagnetically penetrable ones, are nearby. This is due to the relative ease with which the FDTD method accommodates modeling of volumetric electromagnetic interactions with materials as compared to the Method of Moments.

Earlier work [1] has shown that the FDTD method could compute the self impedance of a wire antenna in three dimensions, however, the approach used in [1], plane wave incidence, did not lend itself to mutual coupling calculations. Accurate self-admittance FDTD results for two-dimensional antenna geometries were presented in [2]. In this paper we demonstrate both self and mutual admittance FDTD calculations for three dimensional wire antennas.

(NASA-CR-190100) FINITE DIFFERENCE TIME DOMAIN CALCULATIONS OF ANTENNA MUTUAL COUPLING (Pennsylvania State Univ.) 15 p CSCL 20N

N92-20442

Unclas
G3/32 0077907

II Approach

The test problem geometry is shown in Figure 1. Two wire dipoles of length 57 and 43 cm are parallel and separated by 10.5 cm. Both are center fed, and are symmetrically positioned. The goal is to determine the self admittance of the driven dipole and the mutual admittance between the two dipoles.

The FDTD computations were made using a three dimensional computer code based on the Yee [3] cell, with second order Mur [4] absorbing boundaries. The problem space was chosen as 61x51x80 cells, with the cell dimensions $\Delta x=\Delta y=0.5$ cm, $\Delta z=1.0$ cm. Making the two transverse dimensions smaller results in a greater length to diameter ratio, so that a thin wire Moment Method code may be used to provide comparison results over a wider band of frequencies. Thinner wires may be modeled in FDTD using sub-cell methods [5,6].

For the FDTD calculations the longer dipole is fed at the center with a Gaussian pulse of 100 volts maximum amplitude that reached its 1/e amplitude in 16 time steps. The time steps were 11.11 picoseconds, the Courant stability limit for the cell size chosen.

During the progress of the FDTD calculations the currents at the center of each dipole were saved for each time step. They were computed by evaluating the line integral of the magnetic field around the dipoles at the center. Along with the applied Gaussian voltage pulse the currents were Fourier transformed to the frequency domain. Then, based on the admittance parameter equations

$$I_1 = V_1 Y_{11} + V_2 Y_{12}$$

$$I_2 = V_1 Y_{21} + V_2 Y_{22}$$

and taking V_1 to be the driven dipole voltage and V_2 zero, we easily obtain the self admittance of dipole 1 and the mutual admittance (since $Y_{12} = Y_{21}$) between the dipoles by dividing the appropriate complex Fourier transforms of V_1, I_1, and I_2.

The Moment Method results were obtained using the Electromagnetic Surface Patch Version 4 [7] computer code. The wire radius for the Moment Method calculations was taken as 0.281 cm, providing the same cross section area as the 0.5 cm square FDTD cells. While the FDTD calculations should be valid up to approximately 3 GHz based on having 10 FDTD cells per wavelength, the thin wire approximation for the Moment Method code becomes questionable at approximately 1 GHz and this was taken as the upper frequency limit for comparison of results.

III Results

Figure 2 shows the Gaussian pulse voltage applied to the 1 cell gap at the center of the longer, driven dipole. Figures 3 and 4 show the current flowing in the center cell of the driven and passive dipole respectively. All are plotted on the same time scale, corresponding to 8,192 time steps. This calculation required approximately 7 hours on a 25 MHz 486-based personal computer.

Figures 5-7 show the magnitude of the Fourier transforms of the voltage and current results of Figures 2-4. The current results indicate the complicated frequency domain behavior of the coupled dipole system.

The self admittance was obtained by dividing the complex Fourier transform of the driven dipole current by that of the Gaussian voltage pulse at each frequency. The results are shown in magnitude and phase in Figures 8 and 9 and compared with ESP4 Moment Method results. Considering the differences in how the feed region is modeled (a 1 cm gap in the FDTD calculations vs an infinitesimal gap in ESP4) the agreement is quite good.

The mutual admittance was obtained in a similar manner, dividing the complex passive dipole current by that of the Gaussian pulse. The results are shown in Figures 9 and 10. Again the agreement is quite good considering the different approximations and assumptions made in the FDTD approach relative to the ESP4 computer code.

IV Conclusions

The capability of the FDTD method to predict mutual coupling between antennas was demonstrated. The test case was two parallel wire dipoles of different lengths, with one driven by a Gaussian pulse. The complex self and mutual admittance results obtained using FDTD showed good agreement with results obtained using the Method of Moments.

V References

1. K. Kunz, R. Luebbers, F. Hunsberger, "A Thin Dipole Antenna Demonstration of the Antenna Modeling Capabilities of the Finite Difference Time Domain Technique", Applied Computational Electromagnetics Society Journal, Summer 1990.

2. J. G. Maloney, G. S. Smith, and W. R. Scott, Jr., "Accurate computation of the Radiation from Simple Antennas using the Finite-Difference Time Domain Method," IEEE Trans. Antennas and Propagat., vol. AP-38, pp 1059-1068, July 1990.

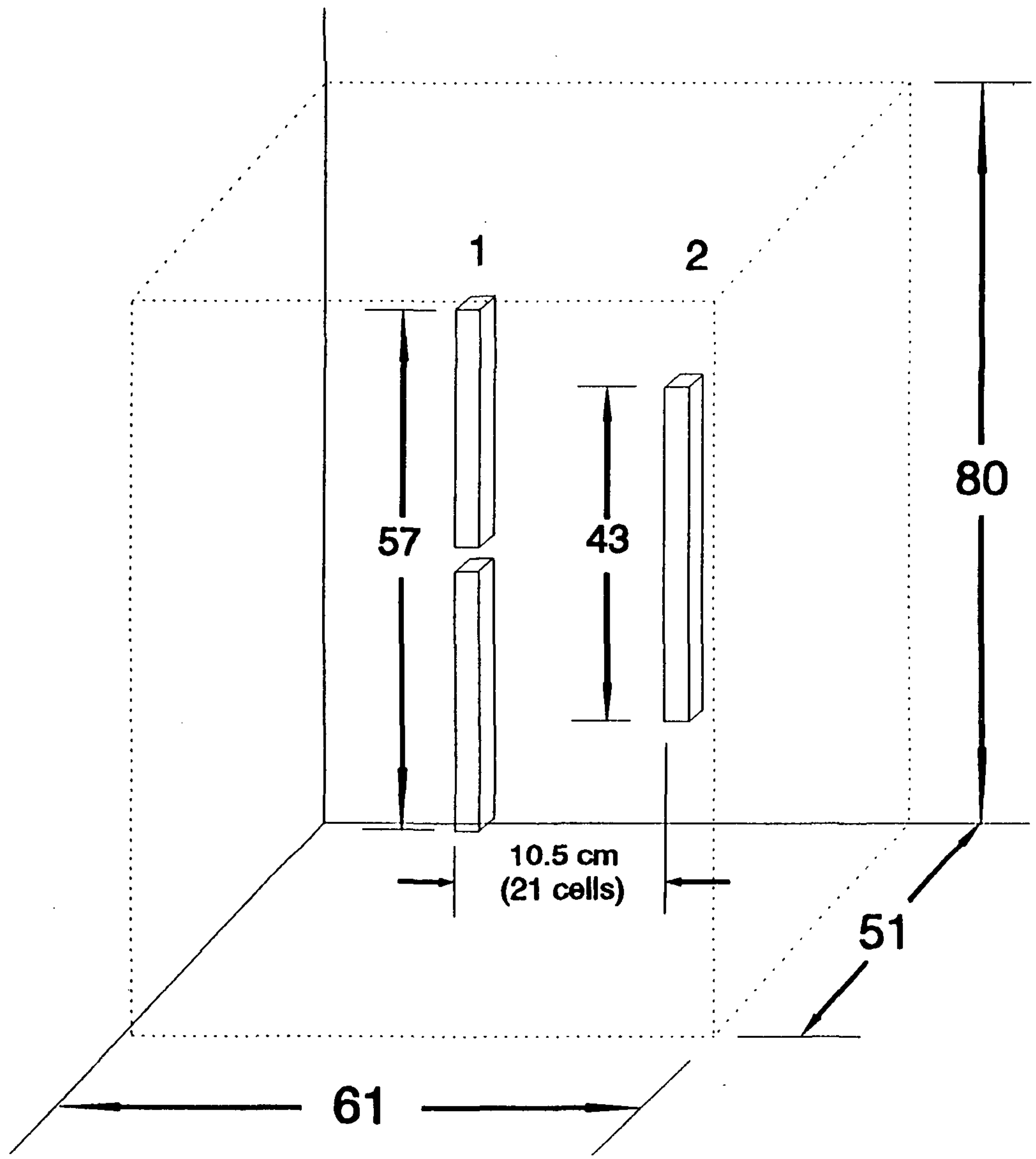
3. K. S. Yee, "Numerical solution of initial boundary value problems involving Maxwell's equations in isotropic media," IEEE Trans. Antennas and Propagat., vol. AP-14, pp 302-307, May 1966.

4. G. Mur, "Absorbing boundary conditions for the Finite Difference Approximation of the Time-Domain Electromagnetic Field Equations," IEEE Trans. on Electromagnetic Compatibility, vol. EMC-23, pp 377-382, November 1981.

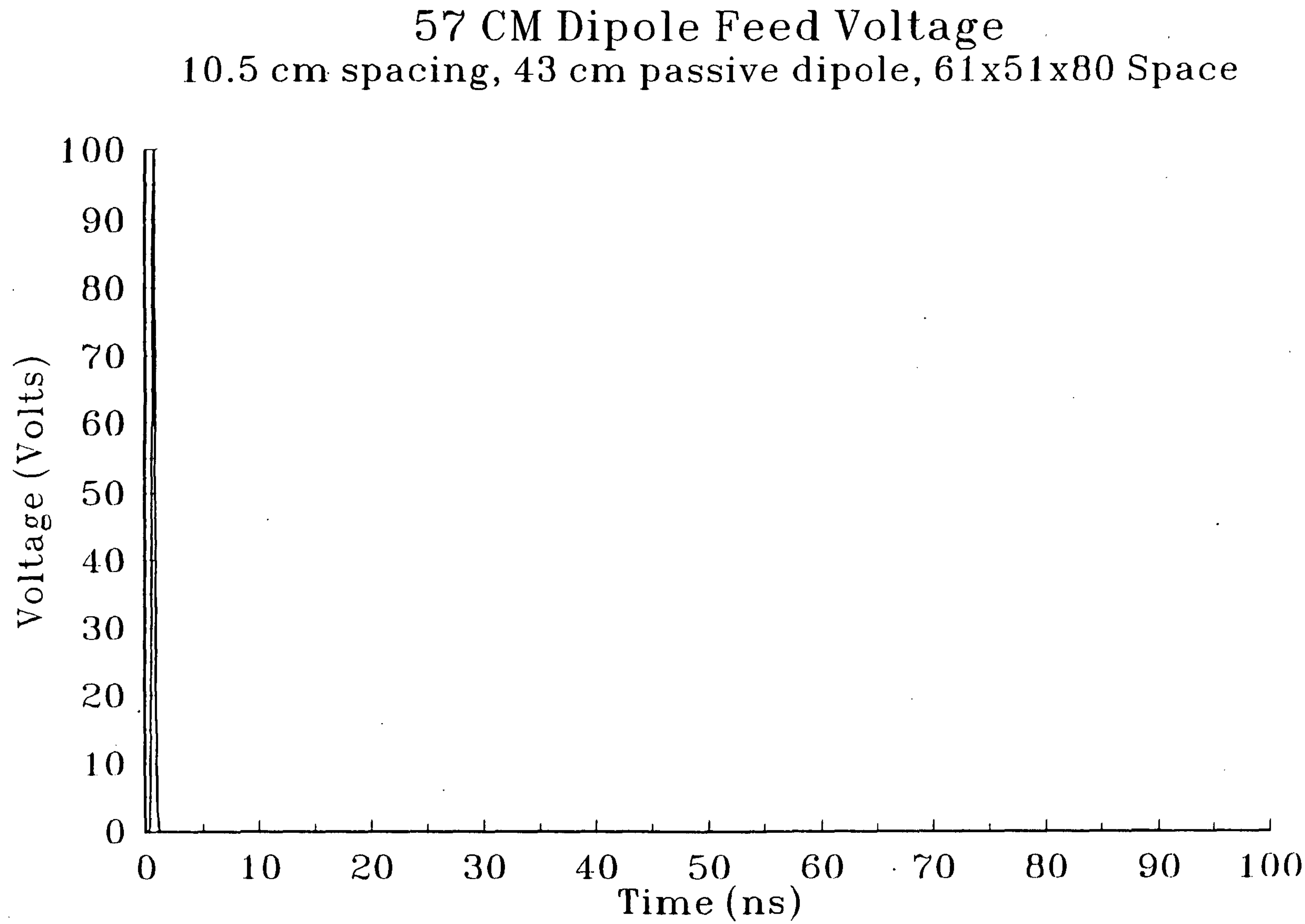
5. R. Holland and L. Simpson, "Finite-difference analysis of EMP coupling to thin struts and wires," IEEE Trans. on Electromagnetic Compatibility, vol. EMC-23, May 1981.

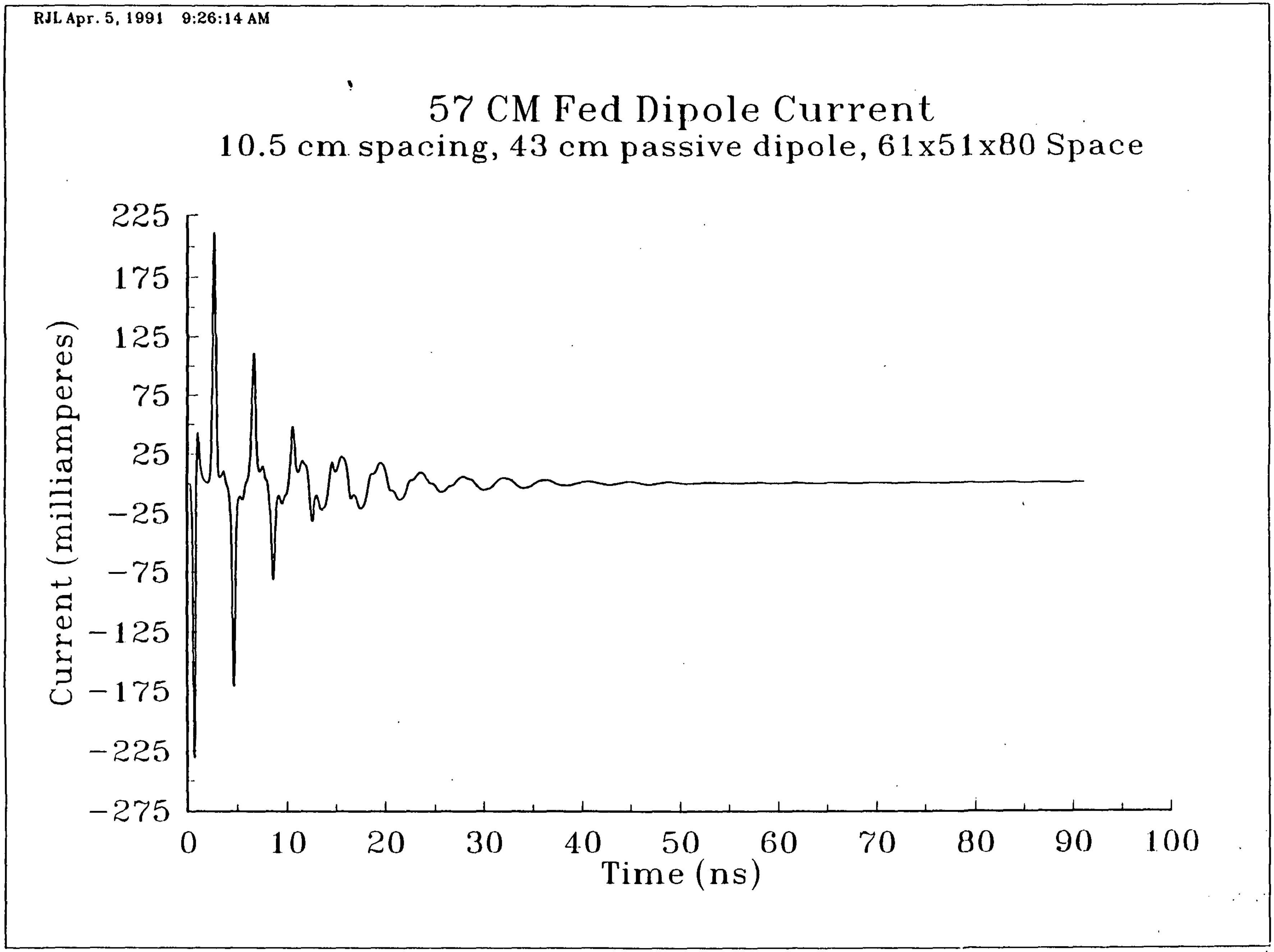
6. K. Umashankar, A. Taflove, and B. Beker, "Calculation and experimental validation of induced currents on coupled wires in an arbitrary shaped cavity," IEEE Trans. Antennas and Propagat., vol. AP-35, pp 1248-1257, November 1987.

7. E. Newman, "A user's manual for the electromagnetic surface patch code: ESP Version IV," The Ohio State University Research Foundation, ElectroScience Laboratory, Department of Electrical Engineering, Columbus, Ohio 43212.

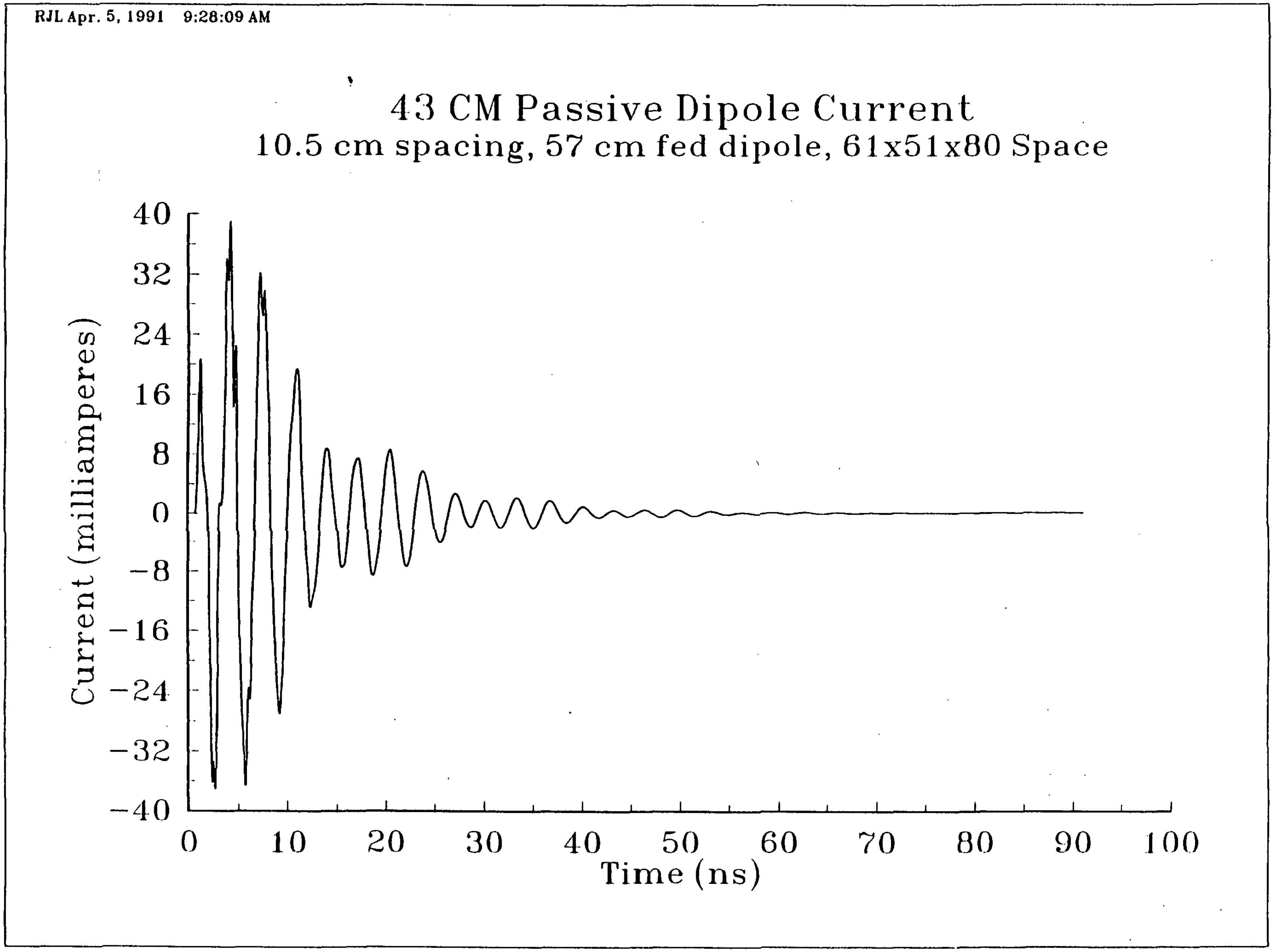

1
2
57
43
80
10.5 cm
(21 cells)
51
61

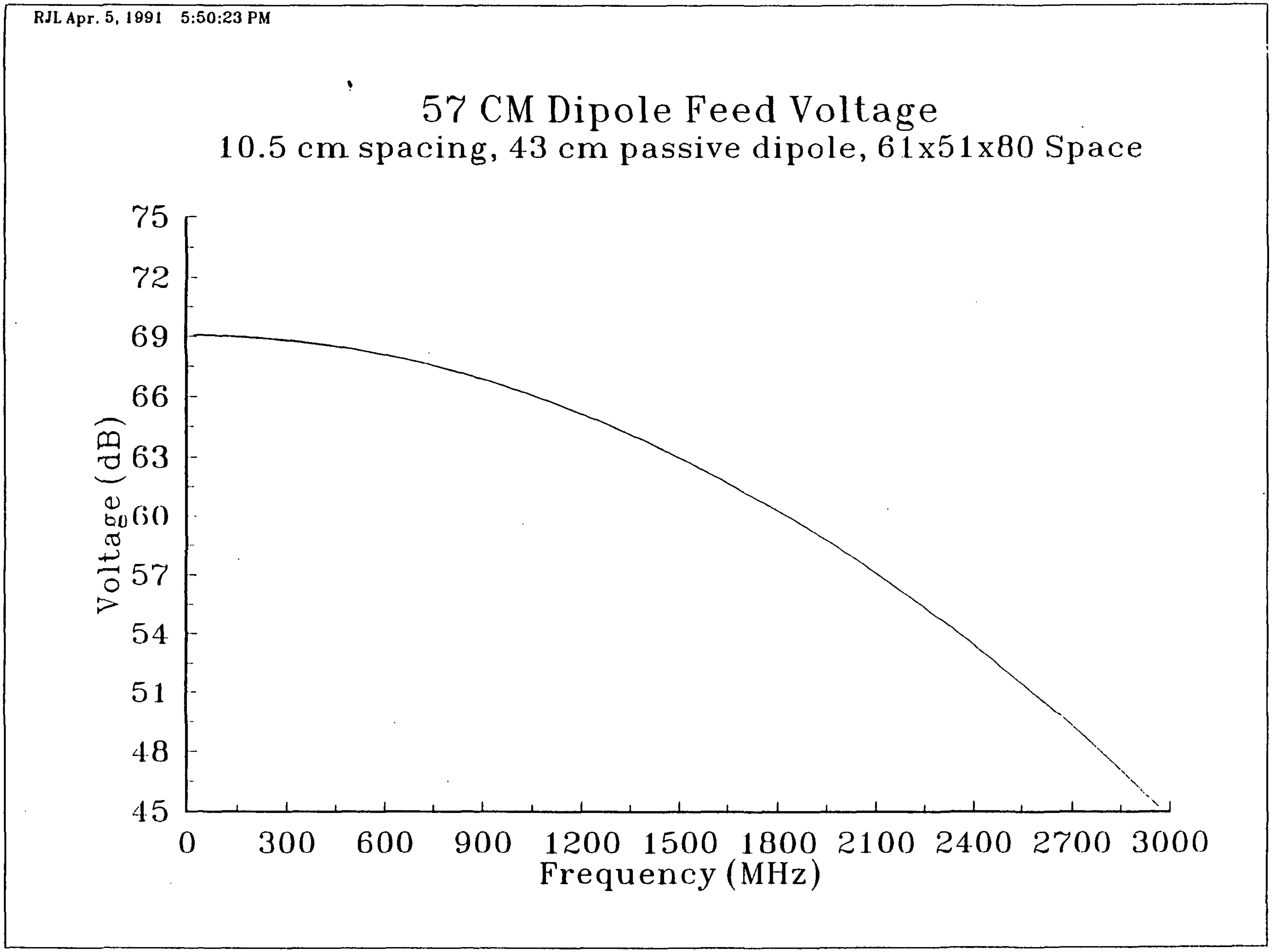
RJL Apr. 5, 1991 9:29:50 AM

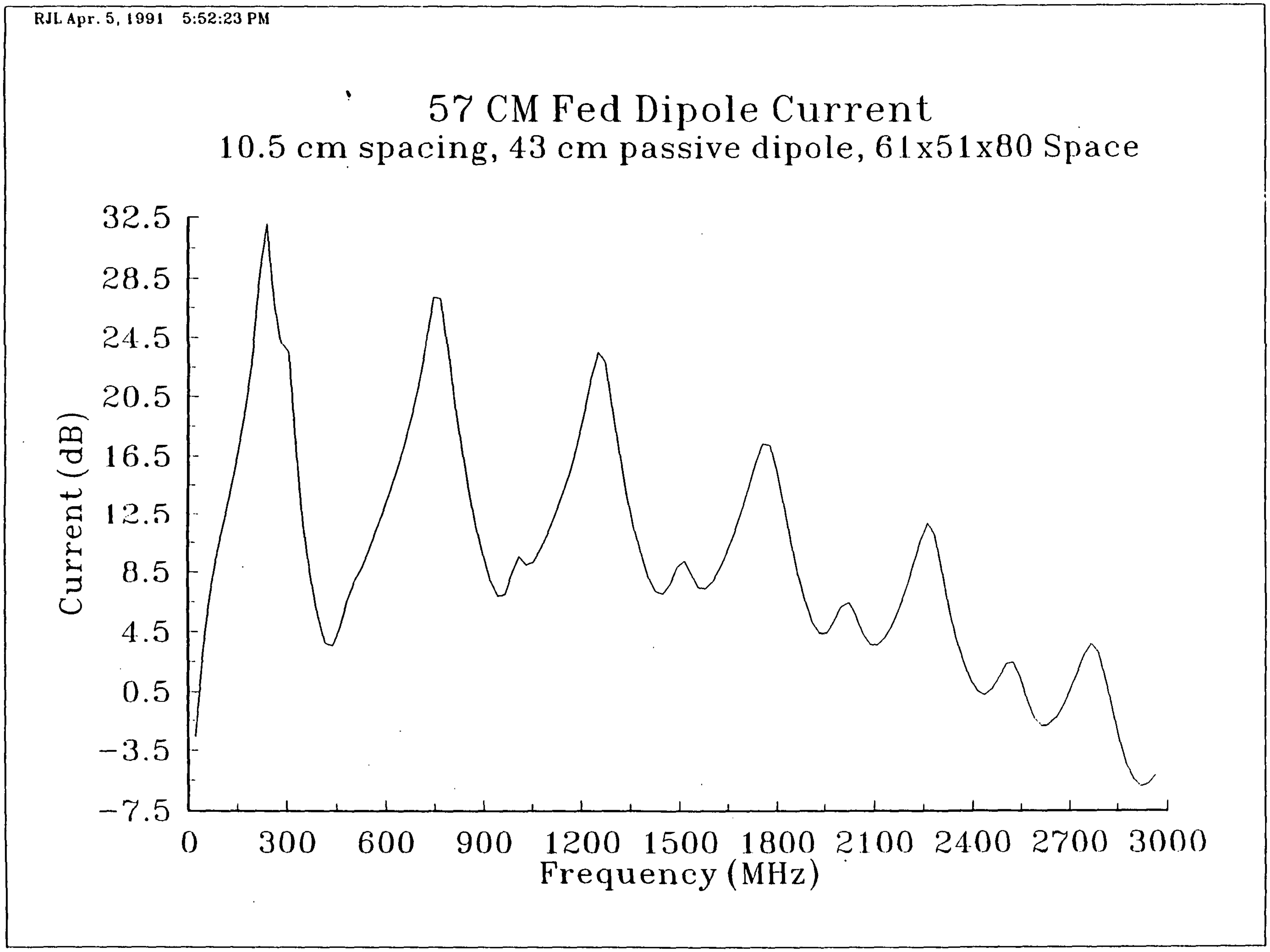



RJL Apr. 5, 1991 9:26:14 AM
57 CM Fed Dipole Current
10.5 cm spacing, 43 cm passive dipole, 61x51x80 Space
Current (milliamperes)
225
175
125
75
25
−25
−75
−125
−175
−225
−275
0
10
20
30
40
50
60
70
80
90
100
Time (ns)

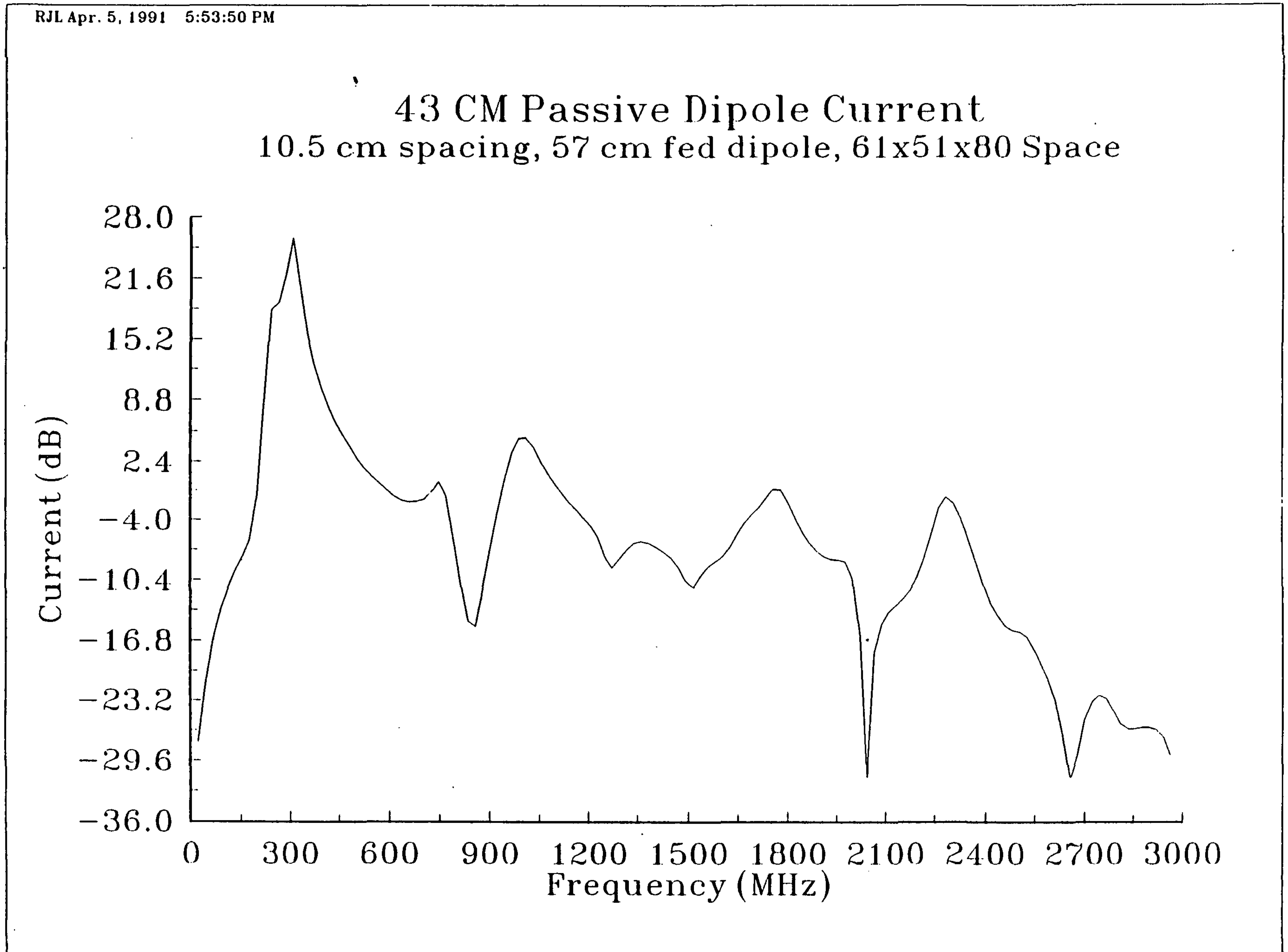
3

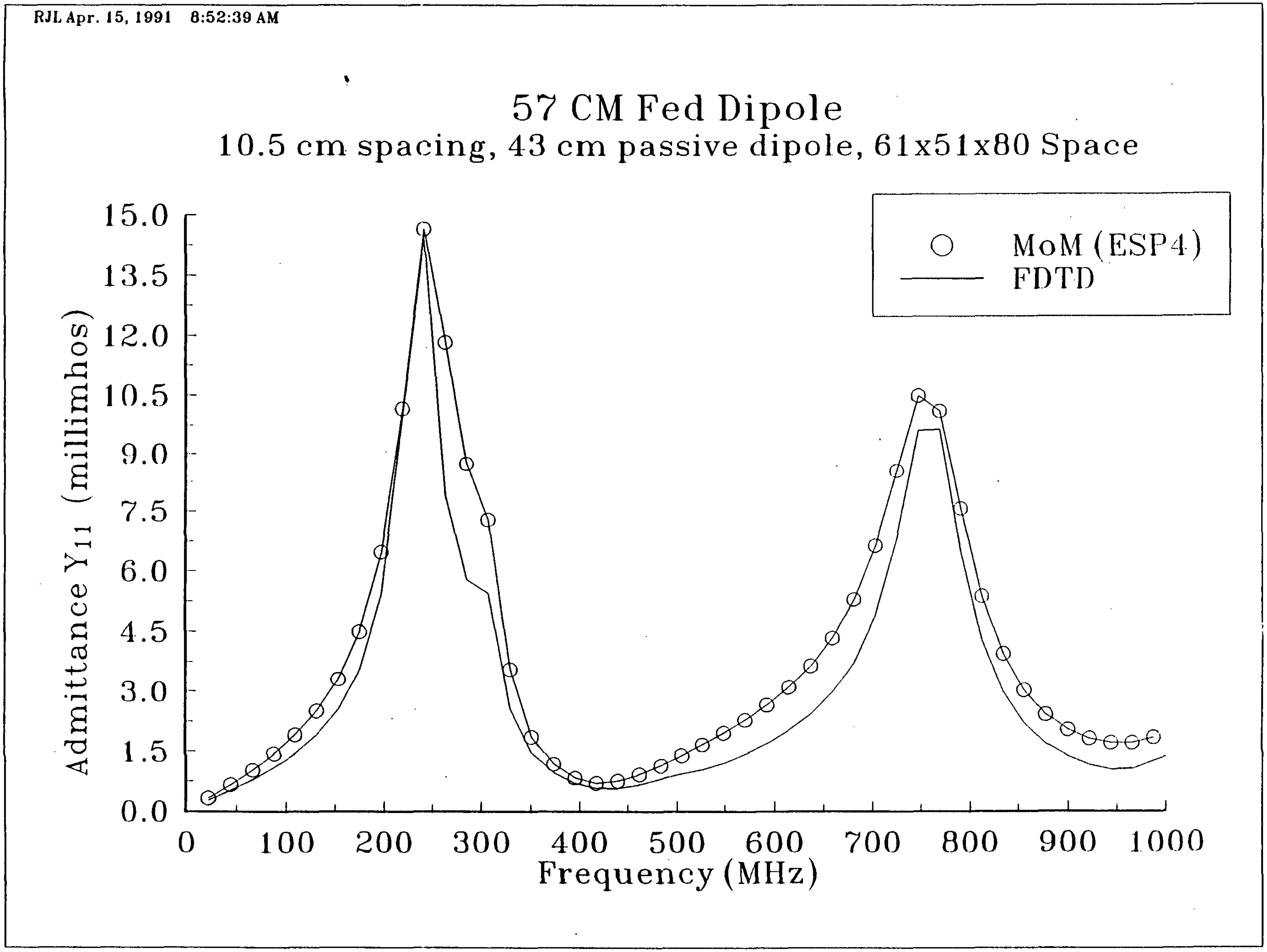

RJL Apr. 5, 1991 9:28:09 AM
43 CM Passive Dipole Current
10.5 cm spacing, 57 cm fed dipole, 61x51x80 Space
Current (milliamperes)
40
32
24
16
8
0
−8
−16
−24
−32
−40
0
10
20
30
40
50
60
70
80
90
100
Time (ns)


RJL Apr. 5, 1991 5:50:23 PM
57 CM Dipole Feed Voltage
10.5 cm spacing, 43 cm passive dipole, 61x51x80 Space
75
72
69
66
63
60
57
54
51
48
45
Voltage (dB)
0
300
600
900
1200
1500
1800
2100
2400
2700
3000
Frequency (MHz)

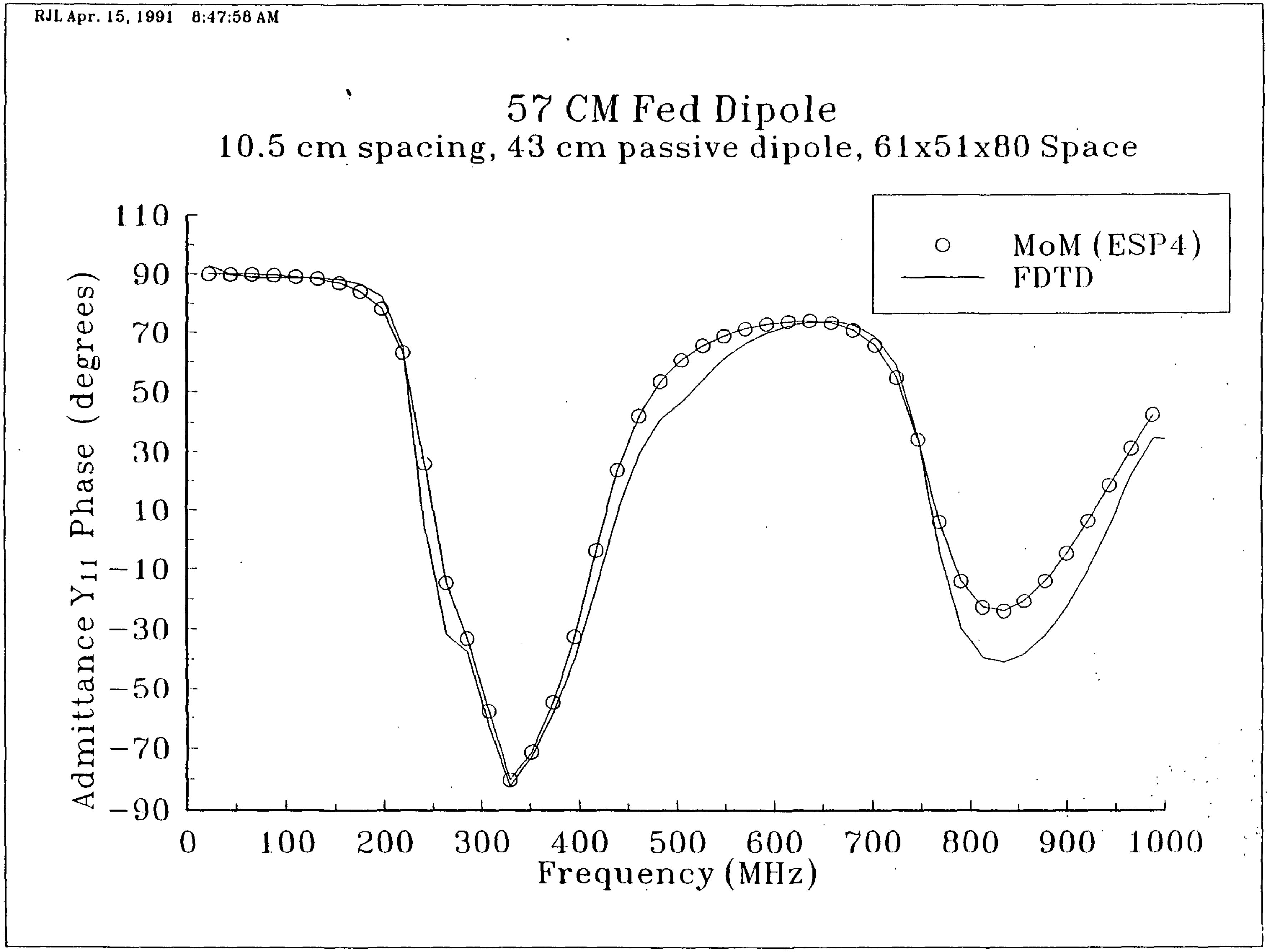

RJL Apr. 5, 1991 5:52:23 PM
57 CM Fed Dipole Current
10.5 cm spacing, 43 cm passive dipole, 61x51x80 Space
Current (dB)
32.5
28.5
24.5
20.5
16.5
12.5
8.5
4.5
0.5
−3.5
−7.5
0
300
600
900
1200
1500
1800
2100
2400
2700
3000
Frequency (MHz)

6

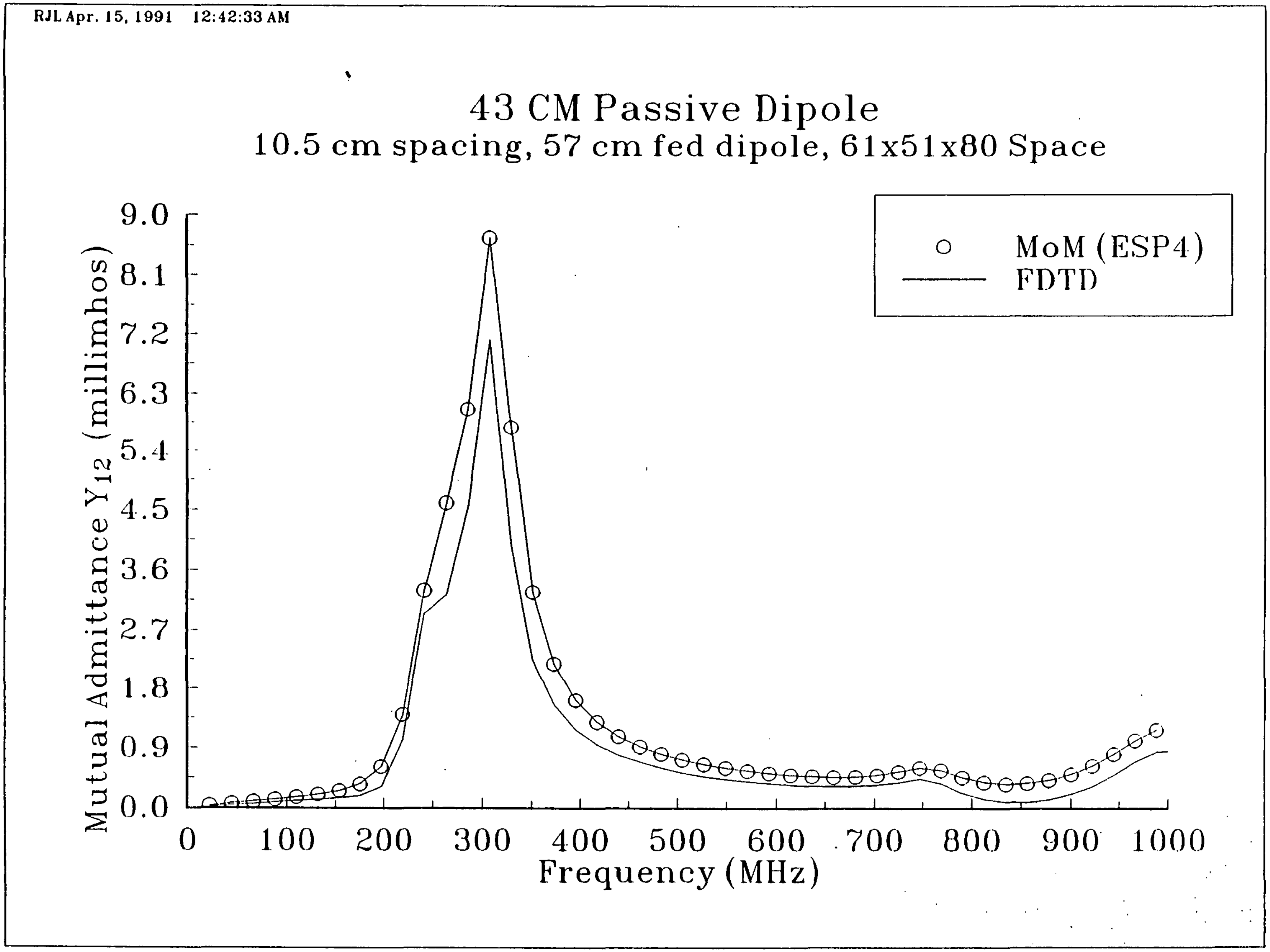

RJL Apr. 5, 1991 5:53:50 PM
43 CM Passive Dipole Current
10.5 cm spacing, 57 cm fed dipole, 61x51x80 Space
Current (dB)
28.0
21.6
15.2
8.8
2.4
−4.0
−10.4
−16.8
−23.2
−29.6
−36.0
0
300
600
900
1200
1500
1800
2100
2400
2700
3000
Frequency (MHz)



RJL Apr. 15, 1991 8:52:39 AM
57 CM Fed Dipole
10.5 cm spacing, 43 cm passive dipole, 61x51x80 Space
MoM (ESP4)
FDTD
Admittance Y11 (millimhos)
15.0
13.5
12.0
10.5
9.0
7.5
6.0
4.5
3.0
1.5
0.0
0
100
200
300
400
500
600
700
800
900
1000
Frequency (MHz)


RJL Apr. 15, 1991 8:47:58 AM
57 CM Fed Dipole
10.5 cm spacing, 43 cm passive dipole, 61x51x80 Space
MoM (ESP4)
FDTD
Admittance Y_{11} Phase (degrees)
110
90
70
50
30
10
−10
−30
−50
−70
−90
0
100
200
300
400
500
600
700
800
900
1000
Frequency (MHz)

9


RJL Apr. 15, 1991 12:42:33 AM
43 CM Passive Dipole
10.5 cm spacing, 57 cm fed dipole, 61x51x80 Space
MoM (ESP4)
FDTD
Mutual Admittance Y12 (millimhos)
9.0
8.1
7.2
6.3
5.4
4.5
3.6
2.7
1.8
0.9
0.0
0
100
200
300
400
500
600
700
800
900
1000
Frequency (MHz)

RJL Apr. 15, 1991 12:43:26 AM